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(54) High molecular weight polybenzimidazole production.

(57) This invention provides a two-stage melt polymerisation process for the production of an improved type of high molecular weight polybenzimidazole, which involves the use of an arylphosphine or arylphosphite polymerisation catalyst.

The process provides poly-2,2'-(m-phenylene)-5,5'-bibenzimidazole of improved colour and Plugging Value, and is further characterised by an inherent viscosity of at least about 0.9 dl/g, and a weight average molecular weight of at least about 140,000.

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HIGH MOLECULAR WEIGHT POLY-  
BENZIMIDAZOLE PRODUCTION

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The present invention relates to an improvement in the production of high molecular weight polybenzimidazoles involving a special two-stage polymerisation process.

Typical processes for preparing polybenzimidazoles are described in Journal of Polymer Science, 50, 511 (1961) and in various United States Patents.

U.S. 3,174,947 (Reissue Patent No: 26,065) describes a method of preparing high molecular weight aromatic polybenzimidazoles by melt polymerising an aromatic tetraamine and a diphenyl ester or an anhydride of an aromatic dicarboxylic acid at an elevated temperature and thereafter further polymerising the product of the melt polymerisation in the solid state. According to this process, in order to produce polymers of sufficiently high molecular weight to be suitable for practical use it is necessary to pulverise finely the product of the melt polymerisation prior to polymerisation in the solid state and to conduct the solid state polymerisation at an elevated temperature under a reduced pressure of less than 0.5 mm Hg or at an elevated temperature and in an inert gas stream over a prolonged period of time. Thus, the process requires several complicated operations. In addition, since the reaction is conducted over a long period of time at an elevated temperature, it tends to form insoluble and infusible polymers.

U.S. 3,313,783 describes a process adapted to overcome the above-mentioned deficiencies, which process involves the solution polymerisation of an inorganic acid salt of an aromatic tetraamine and a dicarboxylic acid or a derivative thereof with heat in polyphosphoric acid. After completion of the reaction the polymer product is separated by pouring the reaction mixture in the form of a polyphosphoric acid solution into a large quantity of water. However, this separation procedure is complicated and it is difficult to recover and re-use the polyphosphoric acid.

Another process for producing polybenzimidazoles is described in U.S. 3,509,108. In the process the monomers are initially reacted in a melt phase polymerisation at a temperature above 200°C. and a pressure above 50 psi (3.515 kg/cm<sup>2</sup>). The reaction product is then heated in a solid state polymerisation at a temperature above 300°C. to yield the final aromatic polybenzimidazole product. The process requires that the initial reaction be conducted at a pressure above 50 psi (3.515 kg/cm<sup>2</sup>), preferably 300 - 600 psi (21.09 - 42.18 kg/cm<sup>2</sup>) in order to control the foaming encountered during the polymerisation.

U.S. 3,555,389 describes a two-stage process for the production of aromatic polybenzimidazoles. The monomers are heated at a temperature above 170°C. in a first-stage melt polymerisation zone until a foamed prepolymer is formed. The foamed prepolymer is cooled, pulverised and introduced into a second-stage polymerisation zone where it is heated in the presence of phenol to yield a polybenzimidazole polymer product. As with the process of U.S. Reissue Patent No: 26,065, this process involves multiple operations and tends to form insoluble polymers.

U.S. 3,433,772 describes a two-stage polymerisation process for the production of aromatic polybenimidazoles which utilise an organic additive, such as an alkane having 11-18 carbon atoms or a polycarbocyclic hydrocarbon, in order to control foaming during the first stage.

Other United States Patents relating to one-stage and two-stage production of polybenzimidazoles include 3,408,336; 3,549,603; 3,708,439; 4,154,919 and 4,312,976.

Technical Report AFML-TR-73-22 (Air Force Material Laboratory, Wright-Patterson AFB, Ohio) describes the production of polybenzimidazole from tetraaminobiphenyl and diphenyl isophthalate in the presence of various catalysts such as ammonium chloride, hydrochloric acid, p-toluene-sulfonic acid, phosphoric acid, triphenylphosphate and boron trifluoride-etherate.

In the said Technical Report (pages 26-27) the data indicate that phosphorus-containing catalysts such as phosphoric acid and triphenyl phosphate are effective for increasing the inherent viscosity of a polybenzimidazole resin. However, there is formation of gel and insoluble black specks which tend to affect adversely the Plugging Value property of the polybenzimidazole products.

There remains a need for an improved method of producing polybenzimidazole which overcomes the various disadvantages of the prior art procedures, and which method yields an improved type of polybenzimidazole product particularly suitable for the formation of fibres having a high melting point and a high degree of thermal stability.

One of the advantages of the present invention is that it provides an improved two-stage polymerisation process for the production of high molecular weight polybenzimidazole in the presence of a phosphorus-containing catalyst.

Another advantage of this invention is that it provides a high molecular weight polybenzimidazole which is characterised by an improved plugging value and an improved colour specification.

Other advantages of the present invention will become apparent from the following description and Examples.

The present invention provides a surprisingly effective manner of overcoming certain disadvantages of the prior art.

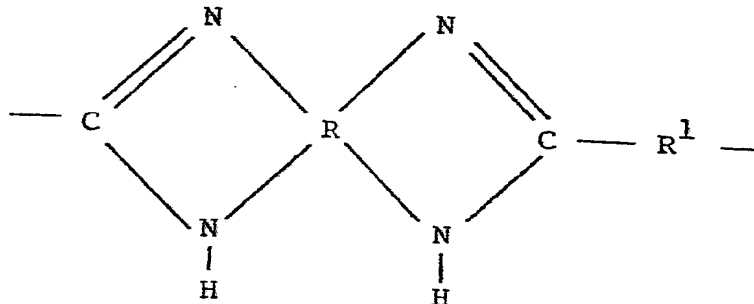
The present invention provides a two-stage polymerisation process for the production of high molecular weight polybenzimidazole from a mixture of (1) at least one aromatic tetraamine containing two groups of amine substituents, said amine substituents in each group being in an ortho position relative to each other, and (2) at least one dicarboxylate ester, which comprises heating the mixture above its melting temperature in a first-stage melt polymerisation zone in the presence of a phosphorus-containing polymerisation catalyst selected from arylphosphines and arylphosphites to provide a foamed prepolymer; and heating the prepolymer in a second-stage solid state polymerisation zone at a temperature above 250°C. to produce high molecular weight polybenzimidazole

product.

In carrying out this process it is not necessary to prepare a mixture of separate items (1) and (2) and heat the mixture in the presence of the catalyst; the same effect may  
 5 be achieved by taking at least one monomeric aromatic reactant having a pair of amine substituents in an ortho position relative to each other and a carboxylate ester group positioned on an aromatic nucleus, and heating the reactant above its melting temperature in a first-stage melt polymer-  
 10 isation zone in the presence of a phosphorus-containing polymerisation catalyst selected from arylphosphines and arylphosphites to provide a foamed prepolymer; and heating the prepolymer in a second-stage solid state polymerisation zone at a temperature above 250°C. to produce high molecular  
 15 weight polybenzimidazole product.

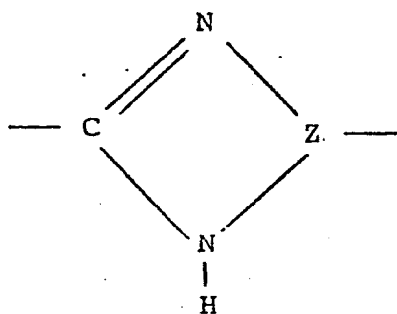
Polybenzimidazoles are a known class of heterocyclic polymers which consist essentially of recurring units of the following Formulas I and II. Formula I is:

20



where R is a tetravalent aromatic nucleus with the nitrogen atoms forming the benzimidazole rings being paired upon adjacent carbon atoms, i.e. ortho carbon atoms, of the aromatic nucleus and R<sup>1</sup> is an aromatic ring, an alkylene  
 25 group (preferably having 4 to 8 carbon atoms) or a heterocyclic ring (such as pyridine, pyrazine, furan, quinoline, thiophene and pyran).

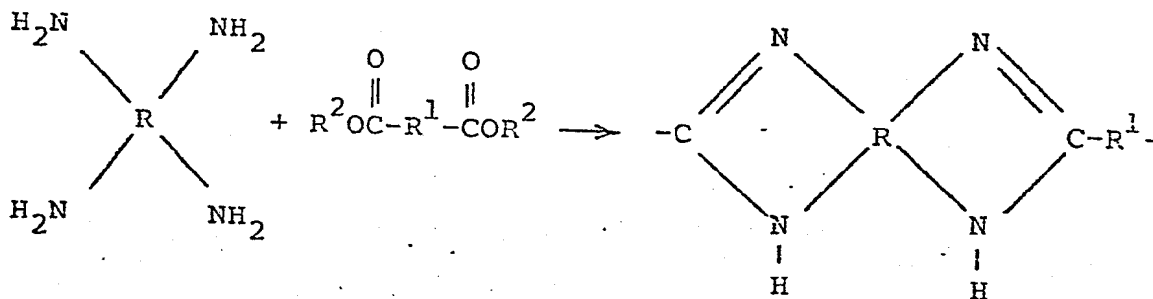
Formula II is:



where Z is an aromatic nucleus having the nitrogen atoms forming the benzimidazole ring paired upon adjacent carbon atoms of the aromatic nucleus.

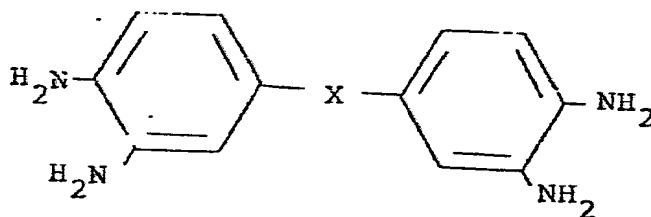
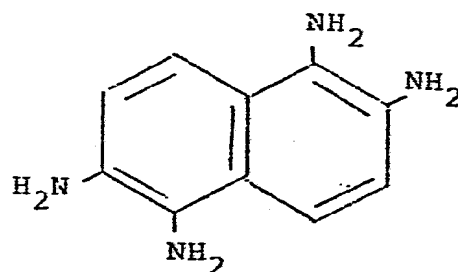
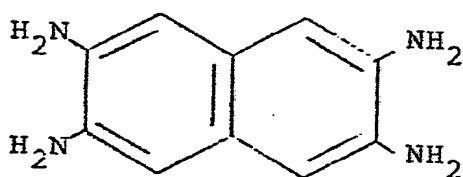
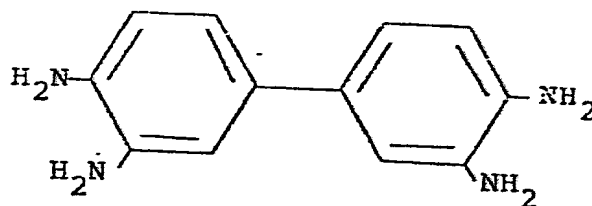
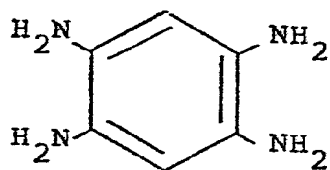
Any of the above polybenzimidazoles represented by the Formulas I and II can be prepared by the process of the present invention.

The following generalised equation illustrates the condensation reaction which occurs in forming the polybenzimidazoles having the recurring units of Formula I:



Such polybenzimidazoles are produced by the reaction of a mixture of (1) at least one aromatic tetraamine containing two groups of amine substituents, the amine substituents in each group being in an ortho position relative to each other, and (2) at least one dicarboxylate ester in which  $R^2$  in the compound shown is a substituent selected from aliphatic, alicyclic and aromatic groups.

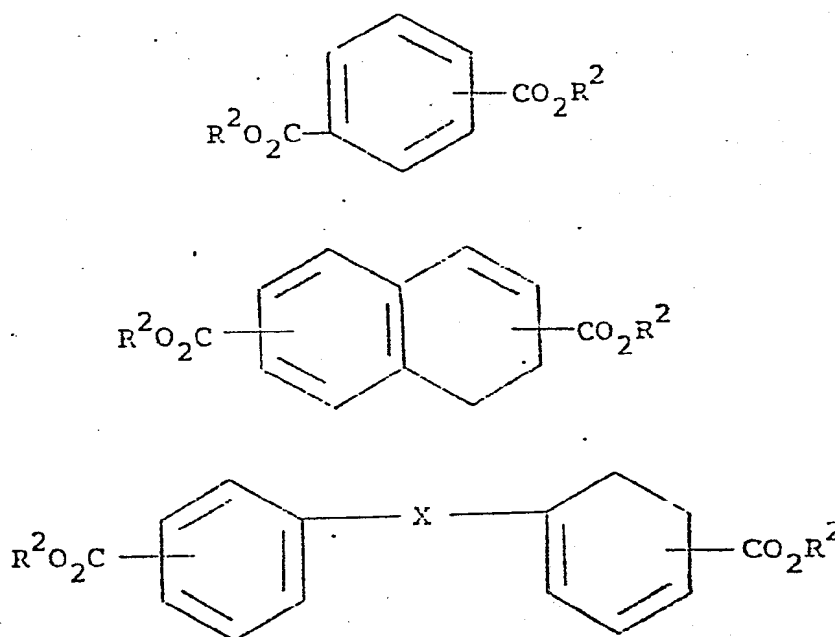
It is advantageous to use as the aromatic tetraamines compounds such as those illustrated below:



where X represents  $-O-$ ,  $-S-$ ,  $-SO_2-$ ,  $-\overset{O}{\overset{||}{C}}-$ , or a lower alkyl group, such as  $-CH_2-$ ,  $-(CH_2)_2-$ , or  $-C(CH_3)_2-$ . Such aromatic tetraamines include 1,2,4,5-tetraaminobenzene; 1,2,5,6-tetraaminonaphthalene; 2,3,6,7-tetraaminonaphthalene; 3,3',4,4'-tetraaminodiphenyl ether; 3,3',4,4'-tetraaminobiphenyl; 3,3',4,4'-tetraaminodiphenylmethane; 3,3',4,4'-tetraamino-1,2-diphenylethane; 3,3',4,4'-tetraamino-2,2-diphenylpropane, 3,3',4,4'-tetraaminodiphenylthioether and 3,3',4,4'-tetraaminodiphenylsulfone. The preferred aromatic tetraamine is 3,3',4,4'-tetraaminobiphenyl.

The dicarboxylate esters which are suitable for use in the production of polybenzimidazoles by the process of the present invention include aromatic dicarboxylate esters; aliphatic dicarboxylate esters (preferably, those having 4 to 8 carbon atoms in the carboxylic acid structure) and heterocyclic dicarboxylate esters wherein the ester groups are substituents upon carbon atoms in a ring compound such as pyridine, pyrazine, furan, quinoline, thiophene and pyran.

The preferred dicarboxylate esters are aromatic dicarboxylate esters such as those illustrated below:



where X and  $R^2$  are as defined above. Typical dicarboxylate esters include diesters of terephthalic acid; isophthalic acid; 4,4'-biphenyldicarboxylic acid; 1,4-naphthalenedicarboxylic acid; 1,6-naphthalenedicarboxylic acid; 2,6-naphthalenedicarboxylic acid; 4,4'-diphenyletherdicarboxylic acid; 4,4'-diphenylmethanedicarboxylic acid; 4,4'-diphenylsulfonedicarboxylic acid and 4,4'-diphenylthioetherdicarboxylic acid. Diphenyl isophthalate is the preferred dicarboxylate ester for use in the process of the present invention.

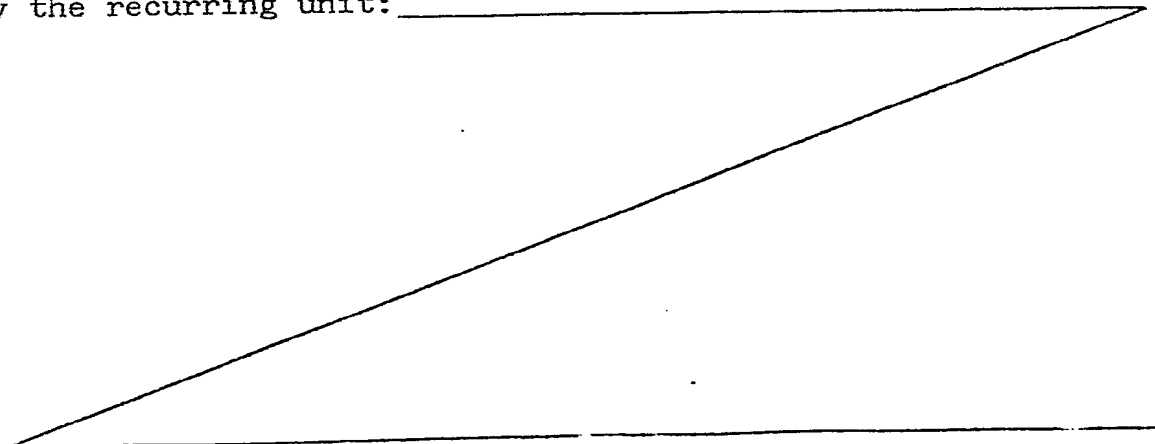


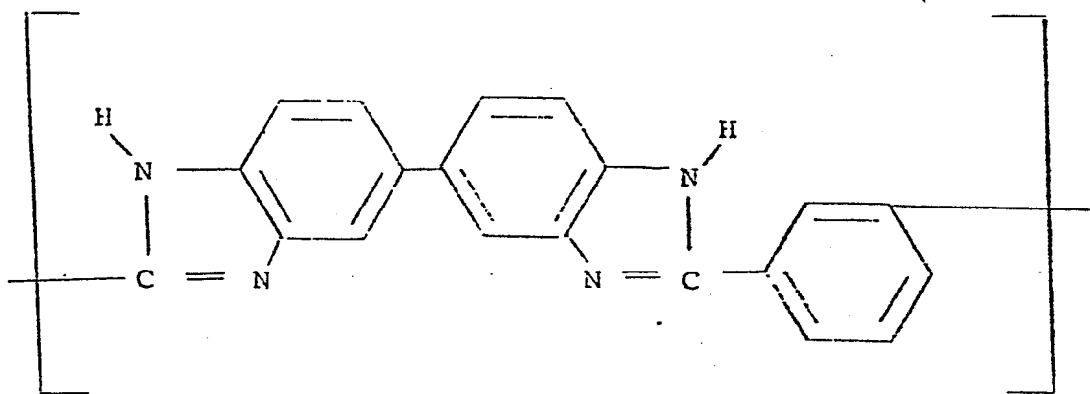
It is preferred to employ the dicarboxylate ester in a ratio of about 1 mole per mole of aromatic tetraamine. However, in order to obtain a product having an optimum molecular weight, it can be advantageous to employ an excess  
 5 (e.g. 0.25 mole percent) of either the dicarboxylate ester or the tetraamine monomeric reactant.

Examples of polybenzimidazoles which have the recurring structure of Formula I and which may be prepared according to the process of the present invention include:

- 10 poly-2,2'-(m-phenylene)-5,5'-bibenzimidazole;
- poly-2,2'-(pyridylene-3",5")-5,5'-bibenzimidazole;
- poly-2,2'-(furylene-2",5")-5,5'-bibenzimidazole;
- poly-2,2'-(naphthalene-1",6")-5,5'-bibenzimidazole;
- poly-2,2'-(biphenylene-4",4")-5,5'-bibenzimidazole;
- 15 poly-2,2'-amylene-5,5'-bibenzimidazole;
- poly-2,2'-octamethylene-5,5'-bibenzimidazole;
- poly-2,6-(m-phenylene)-diimidazobenzene;
- poly-2,2'-cyclohexenyl-5,5'-bibenzimidazole;
- poly-2,2'-(m-phenylene)-5,5'-di(benzimidazole)ether;
- 20 poly-2,2'-(m-phenylene)-5,5'-di(benzimidazole)sulfide;
- poly-2,2'-(m-phenylene)-5,5'-di(benzimidazole)sulfone;
- poly-2,2'-(m-phenylene)-5,5'-di(benzimidazole)methane;
- poly-2',2''-(m-phenylene)-5,5''-di(benzimidazole) propane-2,2
- and
- 25 poly-2,2'-(m-phenylene)-5',5''-di(benzimidazole) ethylene-1,2.

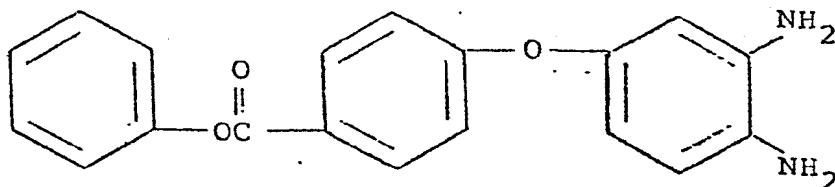
The particularly preferred polybenzimidazole of Formula I prepared by the process of the present invention is:  
 poly-2,2'-(m-phenylene)-5,5'-bibenzimidazole as characterised  
 by the recurring unit: \_\_\_\_\_





The illustrated polymer can be prepared in accordance with the process of the present invention by the reaction of 3,3',4,4'-tetraaminobiphenyl with diphenyl isophthalate.

- 5 The polybenzimidazoles having the recurring units of Formula II can be prepared by the autocondensation of at least one aromatic compound having a pair of amine substituents in an ortho position relative to each other and a carboxylate ester group positioned upon an aromatic nucleus
- 10 (referred to hereinafter as the diaminocarboxylate ester reactant). Examples of such compounds are esters of diaminocarboxylic acids which include 3,4-diaminobenzoic acid; 5,6-diaminonaphthalene-1-carboxylic acid; 5,6-diaminonaphthalene-2-carboxylic acid; 6,7-diaminonaphthalene-1-
- 15 carboxylic acid; 6,7-diaminonaphthalene-2-carboxylic acid and the like. A preferred compound is 4-phenoxy carbonyl-3',4'-diaminodiphenyl ether;



By means of the process of the present invention, high molecular weight polybenzimidazole is produced by reacting the monomeric reactant or reactants described above. The preferred reactants are a mixture of at least one aromatic tetraamine and at least one dicarboxylate ester, as defined  
5 above, with 3,3',4,4'-tetraaminobiphenyl and diphenyl isophthalate being especially preferred. In the first-stage melt polymerisation zone, the monomeric reactant or reactants are polymerised at a temperature above the  
10 melting temperature of the monomeric reactant or reactants in the presence of arylphosphine or arylphosphite acid catalyst to provide a foamed prepolymer.

The first-stage melt polymerisation reaction usually is conducted at a temperature of at least 170°C., and  
15 preferably at a temperature within the range 200°-300°C. In a typical procedure (which may be as described in U.S. 3,549,603), the first-stage melt polymerisation reaction is conducted in a substantially molecular oxygen-free atmosphere for a period of time sufficient to form a pre-  
20 polymer having an inherent viscosity of at least 0.1 (e.g., 0.13-0.3) dl/g. The average reaction time will usually vary from 0.5-3 hours.

In general a pressure of 15-50 psi (1.055-3.515 kg/cm<sup>2</sup>) preferably atmospheric pressure with a flow of nitrogen, is  
25 employed in the first-stage melt polymerisation zone. In a typical run an open polymerisation system is utilised which is provided with a distillation column to remove the water and alcohol which are produced as by-products of the condensation-polymerisation reaction.

30 At the conclusion of the first-stage melt polymerisation reaction, the foamed prepolymer product is cooled and pulverised, and the resultant prepolymer powder is introduced into the second-stage solid state polymerisation zone.

In this zone, the prepolymer powder is heated at a  
35 temperature above 250°C., preferably in the range 320° - 420°C., generally at ambient pressure, for a period of time sufficient to yield a high molecular weight polybenzimidazole product.

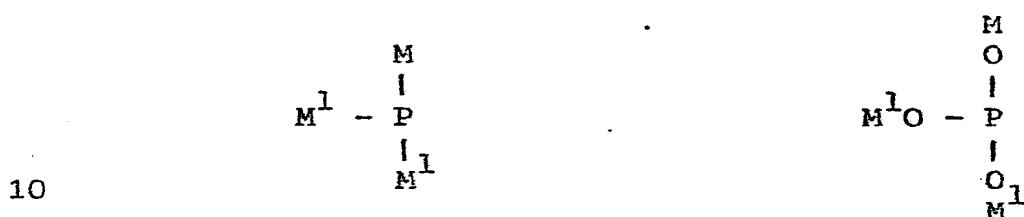
The second-stage reaction is desirably conducted in a substantially oxygen-free atmosphere as with the first-stage reaction. For example, an inert gas such as nitrogen or argon can be continuously passed through the reaction zone during the polymerisation. The inert gas employed should be substantially oxygen-free, i.e., it should desirably contain less than 8 ppm of molecular oxygen. The inert gas may be introduced into the reaction zone at a rate of flow (measured at standard conditions, i.e., atmospheric pressure and temperature) within the range 1-200 percent of volume of the reaction zone per minute. The inert gas can be passed into the polymerisation reaction zone at room temperature or it can be preheated to the reaction temperature.

The second polymerisation stage of the process is conducted for a period of time sufficient to produce a high molecular weight polybenzimidazole product. The inherent viscosity of the polybenzimidazole product is an indication of its molecular weight. The high molecular weight polybenzimidazoles produced by the process of the invention generally exhibit an inherent viscosity of at least 0.7 dl/g when measured at a concentration of 0.4 g of the polymer in 100 ml of 97 percent  $\text{H}_2\text{SO}_4$  at 25°C. Preferably the polymer exhibits an inherent viscosity of at least 0.9 dl/g. In order to assist in obtaining a high molecular weight polybenzimidazole product, the polymerisation in the second-stage zone is conducted for a suitable time, generally at least 0.5 hour, e.g., a reaction period of 1-4 hours.

In the process of the invention, the polymerisation catalyst is usually employed in a quantity of 0.01-5 weight percent, based on the total weight of monomeric material being reacted. In a typical starting mixture the weight of polymerisation catalyst employed is in the range 0.1-1.0 percent, based on the total weight of monomeric material introduced into the first-stage melt polymerisation zone.

An important aspect of the present invention is the use of a specific class of phosphorus-containing polymerisation catalysts. Illustrative of the catalysts are phosphines and phosphites which contain at least one aryl group, and which  
 5 have a total carbon content of 6-20 carbon atoms. The organic substituents can contain non-interfering hetero-atoms, such as oxygen, sulfur, nitrogen and halogen.

Illustrative of preferred catalysts are arylphosphines and arylphosphites corresponding to the formulae:



where M is an aryl substituent, and  $\text{M}^1$  is a substituent selected from hydrogen, alkyl and aryl groups. Examples of suitable catalysts include phenylphosphine, tolylphosphine, naphthylphosphine, butyl-phenylphosphine, diethyl-phenylphosphine, diphenylphosphine, triphenylphosphine, trinaphthylphosphine, methylenedi(methyl-phenylphosphine) and the  
 15 corresponding arylphosphite derivatives.

The arylphosphine or arylphosphite polymerisation catalyst used in the present invention is superior to prior art  
 20 catalysts, such as phosphoric acid or triphenyl phosphate as previously described above, especially in that there is little or no formation of gel and/or insoluble black specks, the presence of which is detrimental to the Plugging Value property. It is believed that the presence of the "plus  
 25 three" phosphorus oxidation state rather than a higher "plus five" phosphorus oxidation state minimises the formation of oxidative by-products. Also beneficial is the presence of at least one aryl group in the polymerisation catalysts used in the present invention.

An important advantage derived from the practice of the two-stage polymerisation process of the present invention is the provision of a high molecular weight polybenzimidazole which has a novel combination of desirable properties.

5 Thus, under optimal operating conditions the process of the present invention provides polybenzimidazole which is characterised by properties comprising an Inherent Viscosity of at least 0.9 dl/g when measured at a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97 percent  
10 sulfuric acid at 25°C.; a Weight Average molecular Weight of at least 140,000; a Plugging Value greater than 1.5; a Gardner Colour less than 10 and the polybenzimidazole is capable of forming a 15 weight percent solution when heated at 240°C. for two hours in dimethylacetamide solvent containing 2 weight percent of lithium chloride.

Polybenzimidazole (PBI) molecular weight constants referred to herein are determined by employing a Waters 201 instrument with two porous silica columns (Waters  $\mu$ -Bondagel E-linears) at the concentration of 0.2 g wt/vol  
20 in DMAc containing 2% LiCl. The calculations are based on a calibration curve obtained with eleven polystyrene molecular weight standards with the range between 2100 and 1,800,000, and the PBI molecular weight corresponds to the polystyrene equivalent molecular weight.

25 Number Average Molecular Weight ( $\bar{M}_n$ ) and Weight Average Molecular Weight ( $\bar{M}_w$ ) and Molecular Weight Distribution are related as follows:

$$MWD = \bar{M}_w / \bar{M}_n$$

The double logarithm of Intrinsic Viscosity  
30 (97%  $H_2SO_4$ ) versus Weight Average Molecular Weight (DMAc, 2% LiCl) can be plotted, and the Mark-Houwink equation for PBI molecular weight can be derived from the plot and expressed as

$$[\eta]_{H_2SO_4} = 1.35326 \times 10^{-4} M^{0.73287}$$

The relationship of Intrinsic Viscosity to Inherent Viscosity of PBI in 97% sulfuric acid can be expressed as

$$[\eta] = 1.0585 \cdot \eta_{inh}$$

By using these expressions, the molecular weight of PBI polymers can be estimated from intrinsic or inherent viscosities in a reasonable agreement with the experimental values.

Plugging Value (P.V.) referred to herein is a measure of solution filterability, and is determined from the filtration rate through a fine filter paper. The PBI polymer to be evaluated is dissolved in  $97.0 \pm 0.1\%$  sulfuric acid at a known concentration of 5 to 7%. The solution is prepared by weighing the desired quantity of sulfuric acid (e.g., 95 grams) into a 250 ml glass-stoppered Erlenmeyer flask, and then weighing the desired quantity of polymer (e.g., 5 grams) with the flask. The polymer is dissolved by shaking on a wrist-action shaker for a minimum of two to three days depending upon the Intrinsic Viscosity (I.V.) level (i.e., longer for higher I.V.s). The filtration apparatus consists of a 2" (5.1 cm) stainless steel pressure filter (Gelman Instrument Co.), Model 4240 and Gelman Type A, 2" (5.1 cm) glass filter papers. The solution after shaking is poured into the filter chamber and one atmosphere of pressure from a nitrogen cylinder is applied. Zero time is taken as the first drop reaches the receiver located on a balance below the filtration unit. The weight of the solution that passes through the filter is recorded with respect to time. Data are continuously generated until either the filter is emptied or the filtration rate is very slow as a result of plugging. Calculation of the Plugging Value is as follows:

1. Each time in minutes is divided by the corresponding weight in grams of solution (total) through the filter at that time.

2. The obtained values are plotted against time. The resulting graph is approximately a straight line. The initial curvature is disregarded as well as the last few points if curvature would again exist.
- 5 3. The reciprocal slope of the graph represents the theoretical weight in grams of solution that would pass through the filter in infinite time in order to plug it. This is designated as  $W_{\infty}$ .

$$P.V. = \frac{W_{\infty} \times \text{Concentration}}{\text{Filter Area}}$$

10 Polybenzimidazole Gardner colour referred to herein is a value which is determined relative to the Gardner colour scale (Gardner Laboratory Inc., Bethesda, Maryland).

15 The Gardner colour scale consists of a gradation of twenty colour shades ranging from water-white (1) to dark brown (20). In accordance with the present invention, polybenzimidazole is provided which has a Gardner colour of less than about 10. A typical commercial type polybenzimidazole fibre has a Gardner colour of about 14.

20 The following Examples I - III and V - VIII are further illustrative of the present invention. The reactants and other specific ingredients and conditions are presented as being typical, and various modifications can be devised in view of the foregoing disclosure within the scope of the invention. Examples IV and IX are not in accordance with the  
25 invention and are given for comparative purposes.

#### EXAMPLE I

30 Into a three-necked flask equipped with a nitrogen inlet and outlet, mechanical stirrer and a condenser are placed 23.33 g (0.1089 mole) of 3,3',4,4'-tetraaminobiphenyl, 34.67 g (0.1089 mole) of diphenylisophthalate and 0.3 g of triphenylphosphite. The flask is degassed and then filled with nitrogen. The degassing is repeated at least three times. The mixture is heated rapidly with stirring to 225°C.



The stirring is stopped, and the temperature of the reaction mixture is raised to 270°C. and held at that temperature for 1.5 hours. The resulting foamed product is cooled to room temperature and then is ground.

5       The ground prepolymer is placed in a flask and after the degassing step has been repeated the prepolymer is heated at 340°C. for one hour. As listed in Table I, the resulting polybenzimidazole exhibits a weight average molecular weight of 144,027 with a molecular weight  
10 distribution of 3.07, an inherent viscosity of 0.95 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97 % sulfuric acid, and a Plugging Value greater than 5 g/cm<sup>2</sup>.

#### EXAMPLE II

15       A polybenzimidazole is prepared in accordance with the procedure described in Example I, except that 0.9 g of catalyst is employed.

The inherent viscosity of the polybenzimidazole thus produced is 1.19 dl/g when measured in a concentration of  
20 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid at 25°C. The weight average molecular weight and molecular weight distribution are 206,521 and 3.57 respectively. The polymer is completely soluble in DMAc containing 2% lithium chloride.

25

#### EXAMPLE III

A polybenzimidazole is prepared in accordance with the procedure described in Example I, except that a diphenylphosphite catalyst is employed.

The inherent viscosity of the polybenzimidazole thus  
30 produced is 0.94 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid at 25°C. The molecular weight and distribution are 159,096 and 3.17 respectively.

#### EXAMPLE IV

35       A polybenzimidazole is prepared in accordance with the procedure described in Example I, except that no catalyst is employed.

The inherent viscosity of the polybenzimidazole thus produced is 0.56 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid at 25°C. The polymer has a weight average molecular weight of 101,742 and molecular weight distribution of 2.71.

The Plugging Value and Gardner colour of this polybenzimidazole are inferior to those obtained by the process of Examples I - III.

If phosphoric acid or triphenyl phosphate is employed as a catalyst, the Plugging Value and Gardner colour of the polybenzimidazole product generally are inferior to those obtained when the catalyst of the present invention is utilised.

#### EXAMPLE V

Into a three-necked flask equipped with a nitrogen inlet and outlet, mechanical stirrer and a condenser are placed 23.33 g (0.1089 mole) of 3,3',4,4'-tetraaminobiphenyl, 34.67 g (0.1089 mole) of diphenyl isophthalate and 0.3 g of diphenylphosphine. The flask is degassed and then filled with nitrogen. The mixture is heated rapidly with stirring to 225°C. The stirring is stopped and the temperature of the reaction mixture is raised to 270°C. and held at that temperature for 1.5 hours. The resulting foamed product is cooled to room temperature and then is ground.

The ground prepolymer is placed in a flask and after the degassing step is repeated the prepolymer is heated at 360°C. for one hour. As listed in Table II, the resulting polybenzimidazole exhibits a weight average molecular weight of 158,909 with a molecular weight distribution of 2.75, an inherent viscosity of 1.00 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid, and a Plugging Value of 7.33 g/cm<sup>2</sup>.

#### EXAMPLE VI

A polybenzimidazole is prepared in accordance with the procedure described in Example V, except that a tri(p-methoxyphenyl) phosphine catalyst is employed.

The inherent viscosity of the polybenzimidazole thus produced is 0.92 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid at 25°C. The polymer exhibits a weight average  
5 molecular weight of 155,415 and a molecular weight distribution of 2.81. The Plugging Value is 1.6 g/cm<sup>2</sup>.

#### EXAMPLE VII

A polybenzimidazole is prepared in accordance with the procedure described in Example V, except that the catalyst  
10 dimethoxy-phenylphosphine is employed.

The inherent viscosity of the polybenzimidazole thus produced is 1.13 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid at 25°C. The polymer exhibits a weight average  
15 molecular weight of 206,507 and a molecular weight distribution of 3.27. The Plugging Value is 3.89 g/cm<sup>2</sup>.

#### EXAMPLE VIII

A polybenzimidazole is prepared in accordance with the procedure described in Example V, except that a di-n-butoxy-  
20 phenylphosphine catalyst is employed.

The inherent viscosity of the polybenzimidazole thus produced is 1.01 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid at 25°C. The polymer exhibits a weight average molecular  
25 weight of 194,606 and a molecular weight distribution of 2.89. The Plugging Value is 5.49 g/cm<sup>2</sup>.

#### EXAMPLE IX

A polybenzimidazole is prepared in accordance with the procedure described in Example V, except that no catalyst is  
30 employed. The inherent viscosity of the polybenzimidazole thus produced is 0.68 dl/g when measured in a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97% sulfuric acid at 25°C. The polymer has a weight average molecular weight of 113,000 and a molecular weight distribution of  
35 2.56. The Plugging Value is 1.54 g/cm<sup>2</sup>.

As with the polybenzimidazole product of Example IV, the polybenzimidazole product of this Example has inferior properties in comparison with the products obtained with the process of this invention.

TABLE I

## PBI FROM TAB AND DPIP

1.5 Hours at 270°C. (1st. Stage) + 1 Hour at 340°C. (2nd. Stage)

Example No:	Catalyst	Cat., Mole %	I.V. dl/g	$\bar{M}_w$	MWD	P.V. <sup>2</sup> g/cm <sup>2</sup>
I	Triphenylphosphite	1	0.95	144,027	3.07	>5
II	Triphenylphosphite	3	1.19	206,521	3.57	>5
III	Diphenylphosphite	1	0.94	159,096	3.17	>5
IV	None	0	0.56	101,742	2.71	0.19

TABLE II

## PBI FROM TAB AND DPIP

Example No:	Catalyst	1.5 Hours at 270°C. (1st. Stage) + 1 Hour at 360°C. (2nd. Stage)				
		Cat., %*	I.V., dl/g	$\bar{M}_w$	MWD	P.V. <sup>2</sup> g/cm
V	Diphenylphosphine	0.86	1.00	158,909	2.75	7.33
VI	Tri(p-methoxyphenyl) phosphine	0.86	0.92	155,415	2.81	1.60
VII	Dimethoxy- phenylphosphine	0.86	1.13	206,507	3.27	3.89
VIII	Di-n-butoxy- phenylphosphine	0.86	1.01	194,606	2.89	5.49
IX	None	0	0.68	113,000	2.56	1.54

\* Based on DPIP weight

CLAIMS

1. A two-stage polymerisation process for the production of high molecular weight polybenzimidazole from a mixture of (1) at least one aromatic tetraamine containing two groups of amine substituents, said amine substituents in each group being in an ortho position relative to each other, and (2) at least one dicarboxylate ester, which comprises heating the mixture above its melting temperature in a first-stage melt polymerisation zone in the presence of a phosphorus-containing polymerisation catalyst selected from arylphosphines and arylphosphites to provide a foamed prepolymer; and heating the prepolymer in a second-stage polymerisation zone at a temperature above 250°C. to produce high molecular weight polybenzimidazole product.
2. A process in accordance with claim 1 wherein the high molecular weight polybenzimidazole obtained exhibits an inherent viscosity of at least 0.9 dl/g when measured at a concentration of 0.4 g of the polybenzimidazole in 100 ml of 97 percent sulfuric acid at 25°C.
3. A process in accordance with claim 1 or 2 wherein the first-stage melt polymerisation reaction is conducted at a temperature of 200°-300°C. and the second-stage solid state polymerisation reaction is conducted at a temperature of 320°-420°C.
4. A process in accordance with any of claims 1 - 3 wherein both stages of the polymerisation reaction are conducted under an inert atmosphere.
5. A process in accordance with any of claims 1 - 4 wherein the polymerisation catalyst is present in a quantity of 0.01-5 weight percent, based on the weight of the monomeric reactants.
6. A process in accordance with any of claims 1 - 5 wherein the monomeric aromatic tetraamine reactant is 3,3',4,4'-tetraaminobiphenyl.
7. A process in accordance with any of claims 1 - 6 wherein the monomeric dicarboxylate ester reactant has an aromatic dicarboxylic acid structure.

8. A process in accordance with claim 7 wherein the monomeric dicarboxylate ester reactant is diphenyl isophthalate.
9. A process in accordance with claim 1 wherein the polymerisation catalyst is diphenylphosphine, tri(p-methoxyphenyl)phosphine, dimethoxy-phenylphosphine, di-n-butoxyphenylphosphine, diphenylphosphite or triphenylphosphite.
10. A two-stage polymerisation process for the production of high molecular weight polybenzimidazole from a mixture of 3,3',4,4'-tetraaminobiphenyl and diphenyl isophthalate which comprises heating the mixture above its melting temperature in a first-stage melt polymerisation zone in the presence of a phosphorus-containing polymerisation catalyst as defined in claim 1 or 9 to provide a foamed prepolymer; and heating the prepolymer in a second-stage solid state polymerisation zone at a temperature above about 250°C. to produce high molecular weight polybenzimidazole product; wherein the polybenzimidazole exhibits an inherent viscosity of at least 0.9 dl/g when measured at a concentration of 0.4 g of said polybenzimidazole in 100 ml of 97 percent sulfuric acid at 25°C., and the polybenzimidazole has a weight average molecular weight of at least 140,000.
11. A process in accordance with claim 10 wherein the polybenzimidazole has a Plugging Value greater than 1.5; a Gardner colour less than 10 and is capable of forming a 15 weight percent solution when heated at 240°C. for two hours in dimethylacetamide solvent.
12. A two-stage polymerisation process for the production of high molecular weight polybenzimidazole from at least one monomeric aromatic reactant having a pair of amine substituents in an ortho position relative to each other and a carboxylate ester group positioned on an aromatic nucleus, which comprises heating the reactant above its melting temperature in a first-stage melt polymerisation zone in the presence of a phosphorus-containing polymerisation catalyst as defined in claim 1 or 10 to provide a foamed prepolymer; and heating the prepolymer in a second-stage

solid state polymerisation zone in accordance with the provisions specified in any of claims 1 - 5.

13. A process in accordance with claim 12 wherein the monomeric aromatic compound is 4-phenoxy-carbonyl-3',4'-diaminodiphenyl ether.